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Assessment of Pilot Performance Using a Moving Horizon (Inside-Out), a Moving Aircraft (Outside-In), and an Arc-Segmented Attitude Reference Display

Brian P. Self, PhD
Maggie Breun, Brent Feldt
Carlene Perry, M.S.
United States Air Force Academy
HQ USAFA/DFEM
2354 Fairchild Drive, Suite 6H2
USAF Academy, CO 80840-6240
USA

Brian.Self@usafa.af.mil

William R. Ercoline, M.S.
Veridian (AFRL/HEM)
2504 Gillingham Drive, Suite 25
Brooks AFB, TX 78235-5104
USA

Flight symbology offers one of the primary countermeasures that can help prevent and alleviate spatial disorientation. As new helmet-mounted displays (HMDs) are being created, we must develop more effective methods of supplying the pitch and bank information to the pilot. While most flyers have long used the inside-out attitude indicator, or a moving horizon (MH) display, many studies have shown that an outside-in display, or a moving airplane (MP), is more intuitive. However, a recent study at Brooks Air Force Base suggests that a new symbology called the arc-segmented attitude reference display (ASAR) produces even better performance and a faster learning curve than either the MH or MP. If found to be operationally relevant, the ASAR should be considered as a likely candidate for HMD flight symbology.

Students in an introductory flight course at the US Air Force Academy were tested on three different display symbologies, the MH, MP, and the ASAR. The displays were presented on a 17-inch color monitor. The experimental sequence was: (1) practice free flight, daytime scene (2) perturbed flight, nighttime scene, (3) practice unusual attitude recoveries (UARs), nighttime scene and (4) test UARs, nighttime scene. During the UARs, subjects were instructed to first roll the aircraft to level the wings, then recover to straight and level flight as quickly as possible. Six different parameters were analyzed during the study: RMS error in roll and pitch during perturbed flight; time to initial stick input in roll and pitch during the UARs; time to straight and level flight during the UARs; and finally, the number of roll reversal errors during the test UARs.

The subjects had the fastest roll and pitch times to initial stick input when using the ASAR, although this display tended to have slightly poorer subjective ratings. The MP display had a slightly faster time to roll input than the MH, but the pitch inputs were identical. Based on these results, the ASAR display is the most effective at portraying attitude information.

Introduction

Human factors researchers have investigated different forms of aircraft display symbologies since Sperry and Doolittle performed the first instrument-only flight in 1929. These two pioneers of aviation recognized that the attitude indicator (AI) was of paramount importance in maintaining controlled flight in low visibility environments, and continued to improve upon their design. Today the AI is recognized as perhaps the only way to prevent spatial disorientation, which costs the US Air Force alone approximately $80 million per year (1). To help prevent these mishaps, it is necessary to provide the pilot with the most intuitive and effective AI possible.

Paper presented at the RTO HFM Symposium on "Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures", held in La Coruña, Spain, 15-17 April 2002, and published in RTO-MP-086.

Sperry and Doolittle's AI introduced the inside-out display type that is most commonly used today. This AI shows an artificial moving horizon (MH) that lines up with the horizon that the pilot views while looking straight ahead out of the cockpit. When the pilot banks left, the artificial horizon rolls to the right, mimicking the motion of the true horizon. A small aircraft symbol remains stationary in the middle of the display as a reference point. Pitch information is typically portrayed by a pitch ladder. This moving horizon symbology is approved by the Federal Aviation Administration and has been a recognized international standard by most nations.

A second type of AI was developed in the former Soviet Union, and is used by most countries who fly with Russian-built aircraft. The moving airplane (MP), or outside-in display, depicts roll information directly opposite that of the MH AI. In the MP, the horizon actually remains stationary in the display case while a miniature aircraft rolls within the display. When the pilot rolls left, the miniature aircraft rolls to the left accordingly. The MP AI also displays pitch information using a type of pitch ladder; therefore, these displays are a hybrid design rather than a total outside-in concept. Various researchers have reported that the MP tends to be more intuitive than the MH design and that the MP design may cause fewer control-stick input errors (5,6).

While these two displays are the dominant designs used in the civilian and military communities today, many other displays have been proposed throughout the years. One of the most promising is the Arc-Segmented Attitude Reference (ASAR) or Grapefruit display, first introduced in Germany (3,4). The ASAR consists of an arc that changes its position according to the bank angle; this arc length is dependent on the pitch of the plane. The roll information acts similarly to the MH type of symbology – as the aircraft rolls counterclockwise, the arc actually rotates clockwise. As the aircraft pitches upwards, the arc length gets shorter and shorter – if you are flying straight upwards, there is no arc display at all. If you are flying straight towards the ground, the display becomes a full circle.

The current study examines the performance of pilots while using a moving horizon, a moving aircraft, and the ASAR displays. Subjects were two groups of students either before or after they had taken an introductory flight course. Both objective and subjective data were analyzed to determine the benefits of the different AIs.

Methods

The research was performed at the United States Air Force Academy utilizing cadets in their fourth year of studies. Fourteen students were recruited from the MSS 481 course, Airmanship for Military Aviators. Six of the subjects had already completed the class, while the other eight were enrolled when tested. The local Institutional Review Board approved the protocol and informed consent was obtained from all subjects.

Three different display symbologies were utilized in the study. The first mimicked the current symbology used in most aircraft equipped with a head-up display– we will call it the moving horizon or MH display. Figure 1 shows the aircraft during two different attitudes. When nose low, the pitch ladder is shown with angled dashed lines that actually "point" the pilot back up to the artificial horizon.

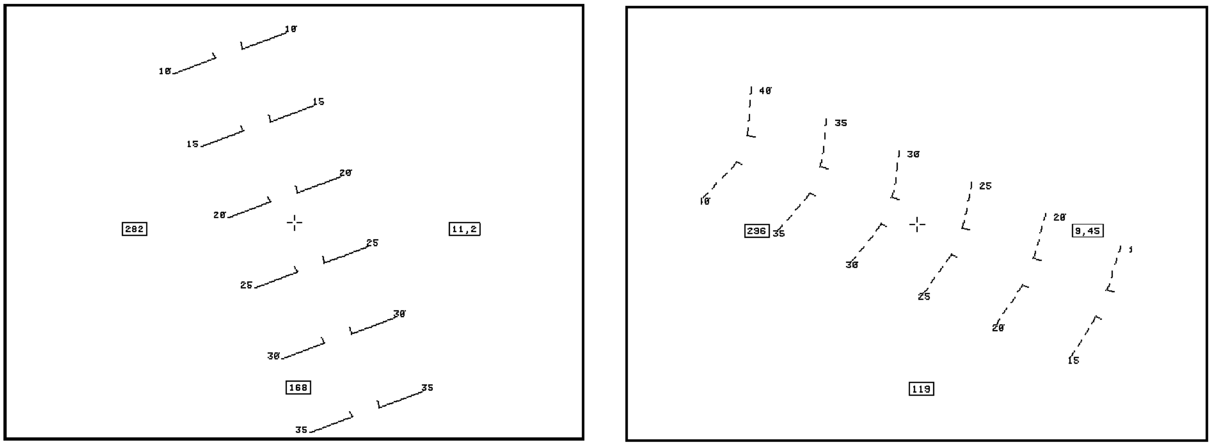

Figure 1. The MH display when flying (a) nose high, inverted, and banked left about 150 degrees and (b) flying nose low, inverted, banked left about 120 degrees.

The second symbology is similar to that used in most Russian made aircraft and will be called the moving aircraft or MP display. As discussed previously, it is actually a hybrid display and utilizes a pitch ladder similar to that used in the MH display above. Figure 2 shows two different attitudes when using the MP symbology. When the aircraft is pitched down so that the horizon line (0 degrees of pitch) is no longer visible, a blinking dashed line appears at the top of the screen to lead the pilot back to straight and level flight.

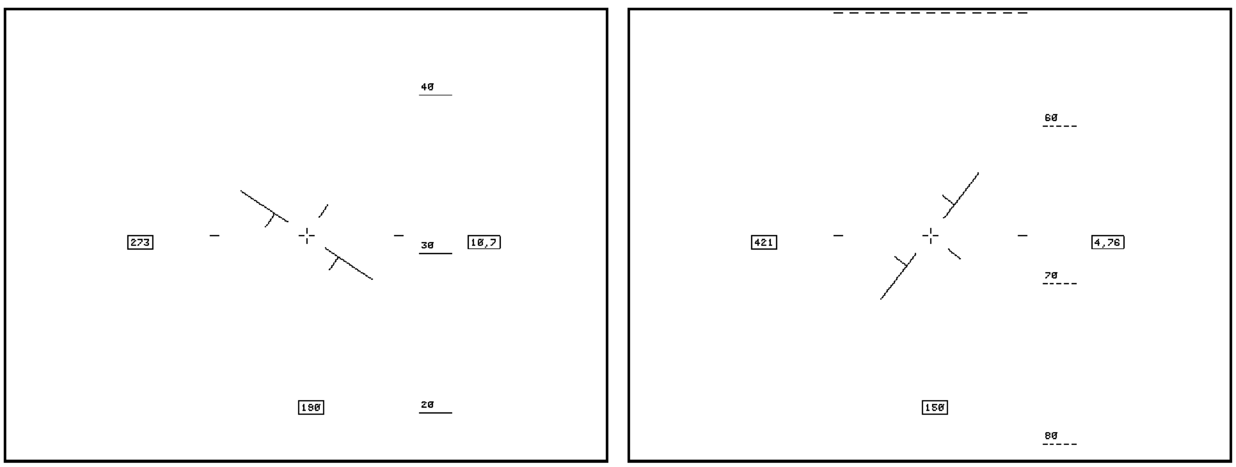

Figure 2. The MP display when flying (a) nose high, banked right about 30 degrees and (b) flying inverted at approximately 120 degrees of right bank.

Finally, the ASAR display is depicted in Figure 3. As discussed earlier, when the aircraft is pitched up the arc length is less than 180 degrees (see Figure 3, left). When the nose is pointed downwards, the arc length increases (see Figure 3, right). The ASAR thus integrates both roll and pitch information into a single display and is an inside-out concept.

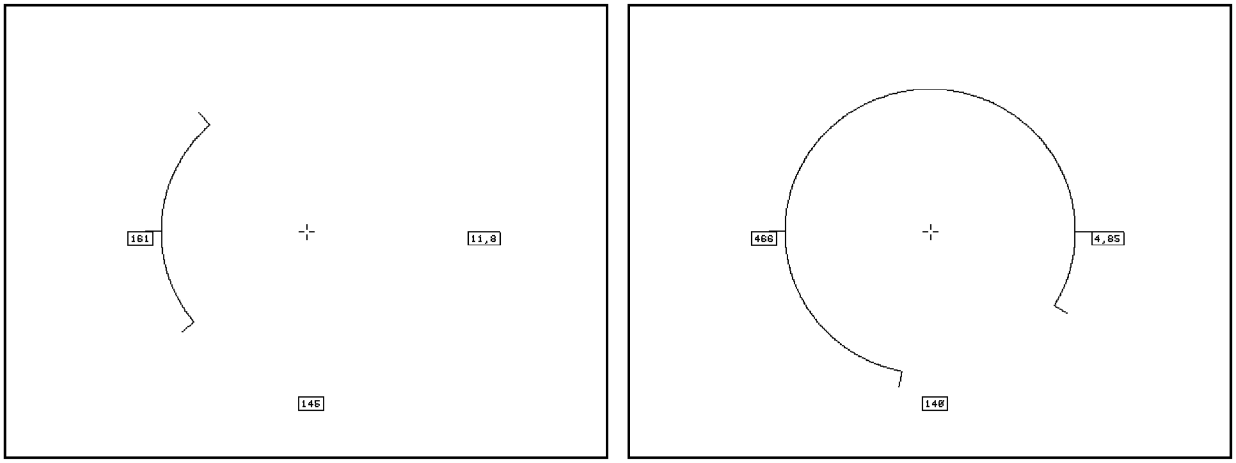

Figure 3. The ASAR display when flying (a) nose high, banked left about 90 degrees and (b) flying inverted at approximately 135 degrees of left bank, nose low.

The test setup is shown in Figure 4. Each subject was seated 30 inches away from a 17-inch computer monitor. A CH Products F-16 Fighter flight stick was used for the control inputs. The Flight Performance Assessment Simulation System (F-PASS) programmed by NTI, Inc (Dayton, OH) was used for the study.

After completing an initial survey, each participant was given a written description of the different display types. They were then allowed up to two full minutes of free-flight, daytime flying on each display. This was followed by a perturbed flight sequence, where each display type was tested for 30 seconds. These tests used a nighttime background scene, as shown in Figures 1-3. The perturbation was created by using five superimposed sine waves with different phase offsets with a gain of 0.5. The algorithm was created randomly, but limits were set for each test sequence to make sure that workload limits were similar for all tests. Roll and pitch root-mean square (RMS) errors were recorded for all perturbed flights.

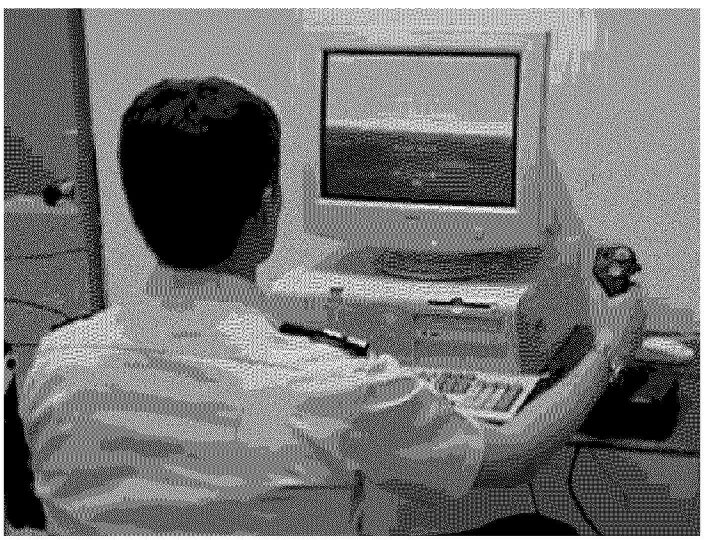

Figure 4. Experimental test setup.

After the perturbed tests, a sequence of eight practice unusual attitude recoveries (UAR) was presented for each display type. When the subjects were ready, they pressed the flight trigger and an unusual attitude was presented. Subjects were instructed to make a roll input to return the wings to level flight, then try to correct the pitch attitude. The subjects were given a maximum of 30 seconds to return the aircraft to straight and level flight (within 5 degrees of pitch and bank, and for 3 continuous seconds). If they could not perform this task successfully on 5 out of 8 trials with a given display type, they were given a second sequence of eight trials to gain proficiency at the task.

Finally, the test UARs were presented. As in the practice UARs, there were eight different conditions for each display type. There were four roll conditions (±30 and ±120 degrees), and two pitch conditions (± 60 degrees). A total of 24 different test UARs was given to each subject, 8 UARs x 3 displays. Both the display type and the UARs were randomized for every subject. After completion of the tests a subjective survey was given to the participants.

Statistical Analysis

The dependent variables were: time to initial roll input, time to initial pitch input, time to recover to straight and level, number of roll reversal errors, and RMS error during the perturbed flights. The data were analyzed with separate repeated measures analyses of variance. Subjective data were also examined.

Results

The perturbed flight RMS error for roll and pitch, the time to initial stick input for both roll and pitch, and the number of roll reversal errors for each display type are shown in Figure 5. For the perturbed flight, the RMS values in roll were not significantly different for any of the displays (p=0.80). The pitch RMS values were significantly lower for the ASAR display (p= 0.003). Because the time to initial stick input data failed a normality tests, a Friedman repeated measures analysis of variance on ranks was performed on the data. For roll inputs, the ASAR had a significantly faster initial stick input times than the MH display (p = 0.023). The initial pitch inputs tended to be faster for the ASAR than for the other two symbologies, but there were no statistical differences noted (p= 0.146). The time to recover to straight and level was not significantly different for any of the displays (ASAR= 11.8 ± 2.0, MH= 11.2 ± 1.5, MP= 11.2 ± 2.0). There tended to be fewer RREs for the ASAR than the other two displays, but there were no significant differences for these values (p= 0.64). Subjective data are summarized in Table 1.

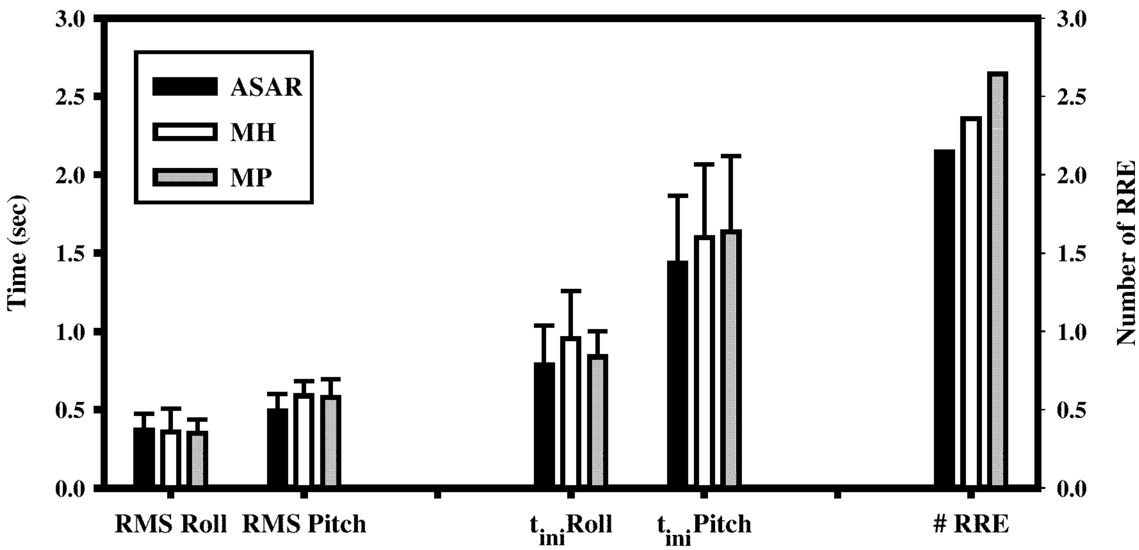

Figure 5. The RMS error in pitch and roll, the time to initial stick input, and the number of roll reversal errors for each display type.

Table I. Mean (s.d.) subjective ratings for the three different display symbologies.

	Was easy to use	**Was confusing to me**	**Was easy to learn**	**I performed well using this display**	**Overall rating**
Scale	***Lickert Scale – 1 strongly disagree, 7 strongly agree***				***1-10***
ASAR	4.57 (1.70)	3.86 (1.51)	4.86 (1.66)	5.07 (1.07)	6.00 (1.84)
MH	5.21 (1.63)	2.36 (1.34)	5.57 (1.60)	5.29 (1.14)	7.93 (1.07)
MP	5.57 (1.40)	2.57 (1.70)	5.93 (1.38)	5.50 (1.45)	7.79 (2.33)

Discussion

The current study is part of a larger research project examining the effects of classroom training on the performance of pilots using three different display symbologies. The MH symbology used in most aircraft follows the familiar inside-out approach championed by Sperry and Doolittle. As has been shown in many other studies, some doubt that this symbology is the most intuitive type of display for the AI. With proper pilot training, however, it has proven to be a successful and a reliable display. It is interesting to note that the MH display resulted in the longest time to initial roll input – the horizon can be somewhat non-intuitive when first presented. When the aircraft is rolled left, the artificial horizon is actually banked to the right, causing a control-symbology movement mismatch.

The MP display is similar to those used in Russian built aircraft. The roll display is an outside-in design, while pitch information is provided by a pitch ladder (similar to the MH design). Several studies have shown that this may be more intuitive than an inside-out display. The initial roll input was somewhat faster than the MH display, and can be explained by the fact that the aircraft mimics the stick input. Since both the MH and MP designs portray pitch information using a pitch ladder, it is not surprising that the time to initial pitch input was similar for the two displays.

The ASAR performed well in the study, having the fastest stick inputs in both roll and pitch. It also provided the smallest RMS error in pitch, which suggests that the changing arc length is an efficient means in which to supply pitch information. It is also interesting to note that the subjective ratings for the ASAR tended to be the poorest of the three, even though the students had their highest performances using the ASAR. This may be explained by the fact that most people are not familiar with this concept.

The results can be compared to a recent study that examined the use of the ASAR on a helmet-mounted display (HMD). In that study, the ASAR had the fastest roll input times (pitch information was not recorded), the fastest recovery, the fewest roll reversal errors, and was the most preferred. The subjects in the HMD study were all experienced pilots (2). The times for initial stick input were quite a bit faster for the cadets than for these pilots – this may be indicative of the students trying to complete the task as rapidly as possible.

Conclusions

The ASAR continues to prove itself, whether with experienced or novice pilots. Continued studies with cadets with varying levels of flying experience and expertise can help determine the most efficient display symbologies to use in future aircraft. These studies can eventually be performed using HMDs in simulators and even in flight at the US Air Force Academy.

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